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ABSTRACT

Three models of skill acquisition are proposed: (1) Nonsituational, (2) Intermediate, and (3) Situational. It is argued that only the third can account for highly skilled performance. The type of emergency training program each suggests and the level of pilot performance that each can be expected to produce is then investigated. We conclude that only training based on the situational model could possibly produce highly skilled emergency response behavior.

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THE SCOPE, LIMITS, AND TRAINING IMPLICATIONS OF THREE MODELS OF AIRCRAFT PILOT EMERGENCY RESPONSE BEHAVIOR

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Stuart E. Dreyfus and Hubert L. Dreyfus

Air Force emergency response training programs take different forms depending upon the model of skill acquisition presupposed. In this paper, we shall distinguish three such models and discuss their plausibility. We shall then show what type of emergency training program each suggests, and the level of pilot performance that each can be expected to produce.

I. THE NONSITUATIONAL MODEL OF EMERGENCY BEHAVIOR

A desituationalized (or formal) description of a pilot's emergency behavior capacity would include the following:

1. A list of all cues, each of them recognizable independently of the situation in which they occur, which might need to be taken account of in flying. Such context-free cues we shall call "features." (Features would include, for example, altitude, runway length, engine-fire light, atmospheric and environmental conditions.)
2. An economical and exhaustive grid of descriptive categories for decomposing each feature. (The altitude might be described to the nearest ten feet below 100 feet, to the nearest 100 feet, between 100 and 2,000 feet, and the nearest thousand feet above that. Runway length might be short, medium, or long; fire light on or off.)
3. A selection rule for determining the appropriate descrip-

tive categories for each feature on the basis of specific factors (instrument readings, control tower data, etc.). (Less than 1,000 foot visibility might be classified as "poor," a short runway might be defined as less than 4,000 feet.)

4. A state → response rule specifying the appropriate response for each state, where the specification of the descriptive category of each relevant feature constitutes the state, and where a response is a particular sequence of basic movements. (If a description of the state includes "altitude 200 feet, runway short, position immediately above beginning of runway," the appropriate response might include "pull back on yoke and advance the throttle, etc." These are the movements of an experienced pilot executing a go around.)

An instructor pilot accepting this desituationalized description would teach the rules for determining the state description and the appropriate response for each state. It might be helpful to think of the instructor as directing his training toward the left, i.e., abstract, logical, hemisphere of the trainee's brain.

II. A SITUATIONAL MODEL OF EMERGENCY BEHAVIOR

A situational model explaining a pilot's capacity for successful emergency behavior includes the following five concrete holistic abilities currently associated with the right hemisphere of the brain. Each of these abilities will be explained more fully in what follows:

1. The ability to remember a sizeable set of typical specific situations (paradigms). (E.g., one situation might be a normal landing with strong crosswinds, large crab angle, and good visibility, etc.)
   These memories, like most memories of situations, are incomplete images, with gaps where details are irrelevant to the situation.
2. The ability to perceive the current situation as similar to one of these remembered paradigms.
3. The ability to notice when the current paradigm is no longer adequate for perceiving the current situation. (E.g., "This landing is not normal. I cannot correct the crab angle and stay in the landing envelope.")
4. The ability to experience the current situation as similar to a different and more appropriate remembered paradigm. Associated with each paradigm are various other paradigms which experience has taught are appropriate if the situation fails to fit the current paradigm in various ways.
5. The ability to remember, along with each paradigm situation, an appropriate purposeful action. (E.g., in the

landing situation above, the action might be to execute a go around. The pilot in our example will now perceive the situation in terms of a new paradigm, perhaps low altitude, level flight.)

The remainder of this section will be devoted to an explanation of what we mean by paradigms, and a discussion of the ability to create and use them.

Suppose an instructor devotes a simulator hour to constructing problems involving estimated touchdown point beyond normal landing zone. The instructor has presumably manipulated various factors such as runway length and altitude and has pointed out which variations change essential problem aspects, e.g., the possibility of staying within the approach envelope, feasibility of go around, etc. The point of the exercise is not that the trainee should remember every particular instance, but rather that he synthesize from this experience a picture of one or more typical late touchdown emergency landing situations. Each of these synthesized pictures is called a paradigm. This picture need not be any of the specific situations simulated. Posner [1] has shown that a subject who has been exposed to a series of figures generated by deforming a nominal figure will subsequently pick out the nominal figure as the best example of the series even if it were not included in the original series. Similarly, the trainee forms pictures of one or more typical late touchdown emergency landing situations, which need not be any of the cases actually simulated.

In the above discussion, we postulated the ability to recognize the current situation as similar to an already acquired appropriate paradigm. Learning more about situations involves learning what other situations they may turn into. Hence, associated with each paradigm are those *exit paradigms* which experience has shown might, in the normal course of events, supersede the current paradigm. The situational model is committed to the view that, as events change and a new situation is recognized as similar to one of those expected, similarity recognition is a primitive, achieved without answering the question: "Similar with respect to what?".†

†This ability, although inexplicable from the point of view of an information processing model basing recognition on the identification of primitive features, is compatible with another type of physically realizable processing model. (See Section VI.)

III. AN INTERMEDIATE MODEL OF EMERGENCY BEHAVIOR

Only the behavior of a rank beginner would accord completely with the nonsituational model. On the other hand, only after considerable experience does a pilot acquire the vast number of paradigms necessary for the behavior described in the situational model. In most situations, especially the most common emergency situations, pilots' behavior is best described by an intermediate model which postulates the following four abilities:

1. The capacity to recognize situations using abilities 1-4 of Section II.

Since the pilot with limited experience has only a restricted set of grossly defined paradigms, he requires in addition the following abilities in order to determine a course of action in specific situations.

2. The ability to identify characteristics which stand out in each remembered situation. These characteristics such as crab angle, crosswind, and visibility will be called *aspects*. Aspects stand out with various degrees of *saliency* such as crucial, important or merely relevant. Adjectives describing the nature of an aspect (such as "strong" "large", and "good") will be called *descriptors*.
3. The ability to remember a sizeable set of typical instances (prototypes) of each aspect (e.g., typical good and poor visibilities independent of any specific flying situation) and the ability to assign a descriptor to each

relevant aspect in a situation being experienced, by seeing the specific instance of the aspect as similar to one of these prototypes. (The airplane's position in the landing envelope (aspect) is seen as high (descriptor) because its position is similar to what the student pilot has learned to call "high in the envelope" (prototype) based on several practice landing approaches which were described as "high" by the instructor.)

4. The ability to remember and use maxims. Maxims are procedures which, given the aspects of a situation, their saliencies and their descriptors, specify an action such as go around. These must be distinguished from rules which are procedures for associating a response with a state description. We have thus distinguished performance based on situation → action maxims from performance based on state → response rules as described in Section I.

The remainder of this section will further explain aspects and descriptors and discuss a pilot's ability to create and use them.

<u>Aspect:</u>

A paradigm has distinguishable aspects. The distinction between what we called "features" in Section I, and what we mean by "aspects" here, is crucial for understanding the difference between the nonsituational and intermediate models. Aspects get their meaning from the performer's experience-based sense of the whole situation, i.e., the paradigm he sees himself in. Since aspects can be specified only on the basis of an understanding of the particular whole situation, *situation understanding is prior to aspect specification.*

Whereas, according to the nonsituational model a pilot pays equal attention to all features such as instrument readings and other objective data which he has been taught are relevant in order to determine what specific situation (state) he currently is in, according to the situational model a pilot is at all times already in a specific situation. From within this situation, the pilot directly sees aspects of the situation. These aspects are based on constellations of instrument readings and other cues, but the pilot is not aware of these cues and can give no rule for computing these aspects. He also sees these aspects as having relatively greater and lesser importance (salience). Many instrument readings and constellations that would be cues indicating aspects of other situations are simply ignored.

Descriptors:

In an actual situation, the appropriate descriptors for the aspects are determined on the basis of similarity to prototypical remembered descriptors. The prototypical descriptors are analogous to typical remembered situations (paradigms) except that prototypes are examples of aspects. Only after a trainee has acquired paradigms and meaningful aspects from real or simulated flying experience can he acquire prototypes. "High in the approach envelope" can only make sense after the trainee has acquired various landing paradigms of which the approach envelope is an aspect. These prototypes can be based on direct experience or textbook examples. As is the case with paradigms, the prototypes acquired need not be any of the specific examples experienced or taught.

Having defined aspects and descriptors, we turn now to their use. Initially, as a performer begins to recognize situations using paradigms, he has only crude characterizations of the sort of situations in whic.. he might find himself. Assuming a paradigm with appropriate aspects and saliencies presents itself, it will be seen as similar to the current situation even if there are significant differences between the descriptor values of the aspects of the paradigm and those of the current situation. Consequently, a large number of real-world situations will be seen as similar to each existing paradigm. Since, depending on how the descriptors are filled in, different actions would be appropriate, the performer at this stage needs explicit procedures for determining the appropriate action for each possible realization of the descriptors. These procedures are called maxims. When situations are recognized in the manner described in the situational model, but actions are calculated on the basis of explicitly recognized aspects and descriptors, one might speculate that a right hemisphere holistic brain process has been coupled with a left hemisphere explicit calculation.

With experience each paradigm will be replaced by several paradigms, each of which is more specific than the original paradigm. For example, the single paradigm, normal landing situation, might be replaced by normal landing with strong crosswinds on a short runway, normal landing with strong crosswinds on a long runway, etc., no matter what the crab angle and position in the landing envelope. These paradigms in turn will be further refined. For example, the normal landing with strong crosswinds on a short runway, might be replaced by several paradigms with differing crab angles and positions in the landing envelope. As this refining of situations occurs, the number of different actions evoked by specifying different sets of descriptors (see ability 4 above) is progressively reduced. Likewise, the number of different sets of possible exit paradigms evoked by specifying different sets of descriptors is progressively reduced. Finally, with enough experience in a particular limited type of problem situation, the performer will see as similar to a specific paradigm only situations calling for the same action and normally capable of turning into one or another of the same set of exit situations. At this point, the (right) brain of performers who have often experienced a certain type of situation contains situation/action pairs so that, given the situation, it is not in principle necessary that aspects be recognized and assigned descriptors or that maxims be used in order to determine actions.

Associating actions directly with paradigms, rather than using analytical processing involving aspects and maxims, is behavior in accord with the situational model (see Section II) and produces highly competent performance. Since experience can directly teach the appropriate action, no guiding maxim need exist. This mental process is cognitively economical in that even with vast experience, a performer need acquire far fewer paradigms than there are aspect-salience-descriptor sets since many situations encompassing whole ranges of descriptors can be seen as similar to the same paradigm as long as the action called for and the set of possible exits is the same.

As we discuss elsewhere [2], true mastery comes when the performer is conscious neither of identifying the situation nor of remembering an action, but rather acts spontaneously without necessarily becoming consciously aware of his situation. We are all in this sense masters of our language and of daily tasks like crossing a street. We eventually drive our automobiles in this fashion under most conditions, and some fliers achieve this state after sufficient experience.

IV. MIXED MODELS OF EMERGENCY BEHAVIOR

Two types of mixed cases may sometimes occur. Instead of the pure cases of performances describable in terms of state → response rules or situation/action pairs, a performance might elicit a state → action procedure or a situation → response procedure.

As a general example of a state → action procedure, suppose that after perceiving that the current paradigm of normal flight is not appropriate, a pilot discovers that no appropriate paradigm presents itself. By examining the instrument readings and other available data, he uses theoretical principles learned in training to conclude that a certain mechanical failure has occurred. Knowing the nature of the mechanical failure, he then knows from previous training what appropriate actions to take. Specifically, failure of the aircraft to respond to controls as expected might lead to the pilot's deduction that a certain critical control device is inoperable. He remembers that he has been instructed in such cases to eject, so he performs this action without having to think of the specific movements involved.

Situation → response procedures might be evoked if: (1) an experienced pilot is flying an unfamiliar plane and needs to think about which physical motions bring about desired maneuvers, (2) an experienced pilot has had insufficient recent flying hours in a familiar plane, (3) an emergency failure occurs which the pilot recognizes on the basis of past experience and for which he knows the appropriate actions; however, the failure has also damaged the control system and the pilot must reason out what physical motions will produce the desired maneuvers.

It should be apparent that, depending on his particular experience, a pilot will respond to certain emergency situations in the manner described by the nonsituational model, to others as described by the situational model, to others as described by the intermediate model, and to still others in each of the two mixed ways.

V. LIMITATIONS OF THE NONSITUATIONAL MODEL

It is our contention that it is a mistake to suppose that *all* performances can be described as desituated. We have seen that the essence of the conception of human cognitive processes as desituated is that, given a real-world situation, isolable features can be identified prior to any understanding of the whole situation beyond recognizing it to be a certain general type, and cognitive behavior is generated by strict rules operating on these features. Such a conception makes no appeal to judgment or interpretation when combining the elements in order to determine a response and can thus be instantiated in a digital computer. The *situational* conception holds that cognitive behavior must be viewed contextually. Only after a situation has been recognized can one analyze it in terms of aspects, which of course have meaning only in the particular situation in which they occur. Such aspects stand out (with various saliencies) to someone already familiar with similar specific situations.

In order to determine the relative merits of the nonsituational and situational model, we shall now look at the evidence concerning the appropriateness of each model as a characterization of various types of human behavior.

Initially, we shall contrast the nonsituational and situational models in the areas of perception, categorization, and abstract theory formation. We shall see that in none of these areas can independently identifiable features account for human competence, but that in each case one must appeal to holistic situations. We shall then turn, by way of contrast, to cases in which human subjects do actually *begin* by recognizing features and applying rules, and investigate the change that takes place as the subject gains competence. Finally, we criticize the argument that, in spite of the *prima facie* evidence to the contrary, human beings *must* be using features and strict rules to generate intelligent activity.

On the level of perception, work in Gestalt psychology is generally acknowledged to have shown that human subjects perceive a total integrated whole that cannot be analyzed into parts. The cliche that Gestaltists hold that the whole is more than the sum of its parts misunderstands the significance of this work. What Gestaltists have shown is that the salient features of a percept can only be understood as *aspects of that particular percept*, and cannot be isolated as independently recognizable elements.

Recently, Erich Goldmeier's extension of early Gestalt work on the perception of similarity of simple perceptual figures--arising in part in response to "the frustrating efforts to teach pattern recognition to [computers]" [3]--has revealed sophisticated distinctions between figure and ground, matter and form, essential and accidental aspects, norms and distortions, etc., which are already apparent at the perceptual level even when no recognizable objects are present. Goldmeier has painstakingly shown that no known features of the phenomenal figures can account for these perceptual functions. He conjectures that they can, nevertheless, be explained on the neurological level, where the importance of *pragnanz* or singularity suggests physical phenomena such as "regions of resonance" [4].

While acknowledging the difficulties facing any analysis of *perception* which abstracts from context, modelers in information processing psychology have claimed that, on the higher cognitive levels, objects are categorized by noticing certain isolable features which identify them as members of a class defined in terms of these features [5]. Eleanor Rosch, however, has found that subjects classify objects as being more or less like typical examples of that sort of object.

> [C]ategories appear to be coded in the mind neither by means of lists of each individual member of the category nor by means of a list of formal criteria necessary and sufficient for category membership but, rather, in terms of a prototype of a typical category member. The most cognitively economical code for a category is, in fact, a concrete image of an average member [6].

Rosch's subjects can, for example, pick out more or less typical chairs from a set of objects or pictures and can draw or describe what they consider the best example of a chair without being aware of having isolated any features in the process. When asked to describe these prototypes, subjects characterized the typical chair as having legs, seat, back, arms, being comfortable, made of wood, something that people sit on. In this list note that only "wood" is an isolable feature, where "isolable" means definable apart from a role as an aspect of a chair. Thus, in spite of Rosch's treatment of all information as decontextualized, her data can be used to argue that objects are seen to be similar, not because they share isolable features, but because they have similar aspects which themselves are recognizable only in the context of the objects in which they stand out as prominent.

Formalists might retrench once more, however, and claim that even if common sense categorization of chairs and tables and other everyday objects is too concrete and tied in with human practices to be amenable to decontextualization, it might be easier to produce a nonsituational model in areas involving only intellectual activity. In that case, science would seem to be an ideal subject for nonsituational modeling, since as a detached theoretical enterprise it deals with isolable physical attributes, whose law-like relations can in principle be grasped by any sufficiently powerful intellect, whether human, Martian, digital, or divine.

Yet, according to the latest theory accepted by historians of science, even scientific research requires concrete examples for its success. Thomas Kuhn, the most influential contemporary historian of science, has argued that scientists working in any particular branch of science at any particular time get their understanding of what constitutes acceptable scientific practice, not by embracing some criteria or set of rules, but by following *specific* textbook examples of good scientific work.

> Scientists can agree that a Newton, Lavoisier, Maxwell, or Einstein has produced an apparently permanent solution to a group of outstanding problems and still disagree, sometimes without being aware of it, about the particular abstract characteristics that make those solutions permanent. They can, that is, agree in their *identification* of a paradigm without agreeing on, or even attempting to produce, a full *interpretation* or *rationalization* of it ... . Indeed, the existence of a paradigm need not even imply that any full set of rules exists [7].

Later Kuhn asserts, more strongly:

> I have in mind a manner of knowing which is misconstrued if reconstructed in terms of rules that are first abstracted from exemplars and thereafter function in their stead [8].

Kuhn is aware that unless historians of science can "discover what isolable elements, explicit or implicit, the members of (the scientific) community may have *abstracted* from their more global paradigms and deployed as rules in their research" [9], the way in which a piece of scientific research is seen to be similar to the paradigm will seem to be incomprehensible, and the judgment of similarity, in the absence of a rule-like criterion, will seem to be subjective and arbitrary. Kuhn, however, insists that neither he nor anyone else has ever found such rules or criteria, and thus historians must face the fact that:

> The practice of normal science depends on the ability, acquired from exemplars, to group objects and situations into similarity sets which are primitive in the sense that the grouping is done without an answer to the question, "Similar with respect to what?" [10].

The nonsituational model, however, gains an apparent plausibility from a description of the acquisition of skills. Generally, the beginner starts with the sort of features and rules used in the nonsituational model. For example, a blind person already familiar with curbs who is learning to use a probe to recognize them, will, as a beginner, experience changing pressures in the palm of his hand and interpret these elements as evidence that features such as surfaces, edges, etc. are present at the end of the probe. These features are then used to determine whether the object at the end of the probe falls into a class (curb) defined in terms of these features. Likewise, chess players start with numerical values for pieces, and simple strict rules such as exchange whenever it improves material balance; language students learn grammatical rules; pilots learn the rules for the sequences of operations required to fly their planes.

In each case, as long as the beginner is following such rules, his performance is halting, rigid, and mediocre, and in each case, with experience, comes a two-stage transformation. At first, the performer ceases to use features and rules and becomes aware of aspects and maxims for appropriate actions. (See Section III.) Finally, the performer simply recognizes situations and acts appropriately. (See Section II.) Thus, after sufficient practice, the blind man in our earlier example directly experiences the curb with its characteristic aspects and descriptors (such as abnormally high, curved, etc.) at the end of his probe and uses simple maxims (such as, if the curb is high take a large step up) to direct his actions. Finally, when fully competent, he directly experiences a high, curved curb and automatically steps up. The chess player in the intermediate stage can think out long range strategies on the basis of aspects such as weakness on the king's side and cramped position, which he recognizes through perceived similarity with experienced positions. Finally, his repertoire of remembered positions becomes so vast that the present position is immediately seen as similar to some previously studied position and he recalls an associated strategy and a promising move for achieving it. Likewise, with the abandonment of features and rules, the language learner starts experiencing the language in meaningful units, and finally becomes fluent. The pilot, when he stops concentrating all thoughts on features and rules, at first begins to feel that he is flying the plane, and finally comes to feel that he is flying.

The suspicion that in such cases the features and rules have simply become unconscious cannot account for the fact that, after these transformations, the style of the behavior is radically changed and the performance dramatically improves. Moreover, if the features and rules have simply dropped out of consciousness without in any way being transformed, how can one account for the fact that, if a skilled performer becomes aware of the elementary actions through which he acquired the skill, his performance is even worse than that of a beginner? Polanyi discusses this disintegration and concludes that reflective attention to the features involved in an action "destroys one's sense of the context which alone can smoothly evoke the proper sequence of words, notes, or gestures" [11]. Furthermore, it seems that once the rules have been superseded, they are simply "forgotten." Anyone who has learned to touch type can confirm that if he tries to type by remembering which finger strikes the letter "b", for example, he will be unable to remember which finger to move.

Thus, psychological research, the history of science, and the phenomenology of skill acquisition all point to the inadequacy of the nonsituational model of skilled behavior. Empirical evidence of the failure of this model can also be found in abundance in the field of artificial intelligence, where many nonsituational models have been implemented. Formal computer models cannot recognize faces, accurately read script, or understand simple children's stories. Chess playing programs have been written using grand master players as consultants. Yet, the best desituationalized procedures that these grand masters can invent play chess at only expert level. And this is achieved by looking at three million alternative sequences of moves whereas chess grand masters only consider on the order of 200.

Air Force research has also found evidence against the non-situational model. De Maio et al. studied the visual scanning techniques of pilots by analyzing their ability to detect anomalous instrument readings. The researchers compared the procedures of students and instructor pilots (IPs) and concluded:

> [T]he results indicate: (a) IPs detect errors with greater accuracy than do student pilots, (b) IPs are faster at detecting errors than students, and (c) systematic cross-check patterns did not appear to be employed by IPs while student pilots appeared to utilize systematic patterns.
>
> This superior performance obtained despite the fact that the IPs did not use any detectable scanning pattern [12].

Elaborating on the flexibility exhibited by IPs while not using any discernible rules, De Maio et al. describe a phenomenon which seems to resemble what we called in Section III the ability based on experience to constellate individual instrument readings into aspects.

> Our data suggest that flexibility is a characteristic which pilots have acquired through long experience with the constantly changing demands of flight ... . The improved performance of experienced pilots seems to result from their ability to learn quickly to attend to relevant aspects of the display while avoiding distraction by irrelevant stimuli [13].

We can conclude that evidence contradicts the nonsituational model which seeks to explain *skilled* behavior in terms of the same sorts of features and rules of which the performer often is aware in *acquiring* a skill. Thus, the assumption that there *must* be a desituationalized explanation is at best unjustified speculation. Such speculation has its source in Plato and becomes explicit in Hobbes, who assumed that all phenomena must have a decontextualized explanation. The whole philosophical tradition has sought this explanation; yet, after 2,000 years, philosophers have failed to formalize any aspect of everyday human performance. In spite of the fact that the most influential contemporary philosophers have recently given up the attempt to formalize [14], [15], and in spite of the failures of artificial intelligence, the advent of the digital computer which operates on elements (bits) with rules (programs) has led psychologists, economists, systems analysts, etc., to embrace the nonsituational model.

VI. CAN THE SITUATIONAL MODEL OF SKILLED BEHAVIOR BE EXPLAINED OR CONFIRMED?

The situational model of skilled behavior is completely compatible with the nonsituational model of *novice* behavior. Psychological journals abound with articles statistically analyzing data showing that the behavior of subjects performing unfamiliar cognitive tasks can be modeled by means of rules relating features to responses. However, there are no studies clearly showing that the behavior of highly skilled performers in a familiar real-world task environment can be successfully analyzed in this way.[†]

[†]Three areas of successful computer performance are frequently inappropriately cited as exceptions to this claim. Upon close examination, however, success in all three areas requires artificially restricted environments. This restriction takes three forms:

(1) All the data that exists consists of abstract elements. For example, mathematical manipulation programs such as MATHLAB, whose elements are constants, variables, functions, and operators, use the same heuristic rules as experts and do as well, as do scientific data analyzing programs such as DENDRAL, whose elements are physical descriptions of spectral lines.

(2) The program and expert are restricted to the same quantifiable portion of the data available. For example, medical diagnostic programs such as MYCIN, whose elements are the numerical results of blood tests, etc., and diagnostic programs in clinical psychology, whose elements are personality test score profiles, do as well or better than experts artificially restricted to the same objective data.

(3) The domain is defined by arbitrary rules for combining arbitrary elements. For example, game playing programs such as chess programs, in which the elements are the position and color of the pieces, and the rules of play are specified, perform at expert levels, but only because the character of the domain allows the program to substitute brute force calculation for human Gestalt perception.

The simulation of an anonymous bank trust investment officer [16] is sometimes cited as a successful nonsituational model of highly skilled performance in a real world environment. However, it should be noted that (1) a trust investment officer's options are severely restricted by law, (2) this particular officer restricted himself to simple quantitative data about specific stocks, and (3) the officer handled small, individual accounts which banks, if they consider them all, consider too inconsequential to occupy much time or effort. This suggests that the officer handling these small accounts would not be likely to have the skill of the officer entrusted with investing large accounts, let alone the officer in charge of investing the bank's own money.

Scientific methodology dictates that if one already has an explanation of a certain range of phenomena (in this case novice performance) one should assume this explanation holds for the whole range of related phenomena (in this case skilled performance, including the situational skills discussed in Section V) until an alternative explanation is proposed which can better account for the recalcitrant phenomena. We shall now argue that there are two kinds of scientific explanation, and that although the situational model cannot provide the kind of explanation of skill that the nonsituational model attempts to provide, it is nonetheless compatible with an alternative kind of scientific explanation of skilled behavior.

Modern science admits of two kinds of explanation:

1. Subsumption under covering laws. In such an explanation a specific case is shown to be an instance of a general regularity, covering a variety of phenomena. Thus to explain why a particular apple falls from the tree we can see the event as an instance of the law of gravitational attraction, which also explains the motion of planets, pendulums, etc.
2. Mechanical or systematic. In such explanations, one singles out functional components and accounts for an overall capacity in terms of the capacities and arrangement of the components. For example, one explains how an internal combustion engine works by talking about the capacities and arrangement of the spark plugs, carburetor, distributor, pistons, etc.

Underlying all explanations in those sciences which have achieved success in prediction and control are the basic covering laws of physics (relativity theory, quantum mechanics, and electromagnetic field theory) for which one does not need to seek a mechanical explanation.

The information processing model currently accepted in cognitive science (see Section I), with its rules, flow charts and complex data structures made up of elements, is a mechanical explanation.

Our situational model (see Section II) is not an explanation in either of the above senses, but rather a detailed description of the ability, involved in skilled performance, to directly perceive situations as similar. While clearly not a mechanistic explanation, this account is not a covering law explanation either, since this ability has not been shown to be a special case of a more general regularity. It is, however, possible to conceive of a covering law explanation of the abilities posited by the situational model, since there exist devices using optical holograms (explained by the covering laws of optics) which actually do recognize similarity without requiring feature analysis. These devices, used, for example, for finger print recognition, work as follows. An optical hologram is prepared by illuminating an arbitrary scene with coherent light. When the light reflected by a reference object in this scene is used to illuminate this hologram, the interference pattern performs what mathematicians would call taking the cross correlation of the complex amplitude transmittances from the scene and the reference object. Bright spots appear virtually instantaneously indicating the presence and location of each similarly oriented occurrence of the reference object in the scene. Moreover, the more intricate the shape of the object to be recognized, the more reliable the instantaneous recognition [17].

Whether or not the brain actually instantiates holographic processes, the existence of recognition devices based on similarity rather than features shows that at least one form of situational recognition is explanable and could be carried out by the brain. The full situational model involving remembered typical situations where these memories would include emotions, bodily sensations, tensions between competing goals, etc., might be conceived of as an extension of the above pattern recognition process.

Some scientists actually believe that the brain instantiates something like optical holograms. John Haugeland summarizes their reasons as follows:

> First, [optical holograms can] ... be used to reconstruct a full three-dimensional colored image of an object. Second, the whole image can be reconstructed from any large enough portion of the hologram (i.e., there's no saying which portion of the hologram "encodes" which portion of the image). Third, a number of objects can be separately recorded on the same hologram, and there's no saying which portion records which object. Fourth, if a hologram of an arbitrary scene is suitably illuminated with the light from a reference object, bright spots will appear indicating (virtually instantaneously) the presence and location of any occurrences of the reference object in the scene (and dimmer spots indicate "similar" objects). Fifth, if a hologram combining light from two separate objects is illuminated with the light from one of them, an image of the other (absent) object appears. Thus, such a hologram can be regarded as a kind of "associator" of visual patterns. So some neurophysiological holographic encoding might account for a number of perplexing features of visual recall and recognition, including their speed, some of their invariances, and the fact that they are only slightly impaired by large lesions in relevant areas of the brain [18].

Dr. Karl Pribram, a Stanford neurophysiologist who has spent the last decade studying holographic memory, explicitly notes the implication of this sort of process for decision-making. When asked in an interview whether holograms would allow a person to make decisions spontaneously in very complex environments, he replied, "Decisions fall out as the holographic correlations are performed. One doesn't have to think things through ... a step at a time. One takes the whole constellation of a situation, correlates it, and out of that correlation emerges the correct response" [19].

Definitive confirmation or disconfirmation of the holographic hypothesis will have to await developments in neurophysiology. There are, however, psychological experiments whose results could lend support to the holographic model. Remembered real-world situations are generally too complicated to be used in testing such a model; however, one might be able experimentally to compare the feature detection and the holographic hypotheses in the simpler case where the remembered situation takes the form of an exceedingly familiar visual pattern. The nonsituational model predicts that as one becomes more familiar with a pattern, features might be found with high discriminative value and better heuristics for using them might be developed, but that the recognition process remains fundamentally unchanged. The holographic version of the situational model, on the other hand, predicts that after sufficient exposure the recognition process changes from an analytic one (perhaps in the left hemisphere of the brain) to a holistic one (perhaps in the right hemisphere).

To test these competing hypotheses, one might take subjects such as native readers of Chinese ideograms and test tachistoscopically the exposure time necessary for recognition of characters of varying complexity. The nonsituational model would predict that the average recognition time would increase with complexity of the pattern, whereas the holographic model would predict that the exposure time would be constant and that reliability would increase with pattern complexity. If the prediction based on the holographic model proves to be correct, this would cast doubt on the nonsituational model while tending to confirm the situational one, of which the holographic model is a special case.

VII. IMPLICATIONS FOR EMERGENCY TRAINING

For pilots already proficient in flying under normal conditions, the models of skilled behavior presented in Sections I-III of this paper each suggest a different program of emergency training based on a different account of situation recognition. (We assume below, however, the same method of teaching the skilled pilot to execute an appropriate plan of recovery once the situation is recognized.)† The three models lead to the following three programs:

1. Instruction based on the nonsituational model begins by defining each class of emergency situation in terms of facts whose presence is necessary and sufficient for class membership. Facts would include: constellations of instrument readings, aspects such as strange sounds which would be recognizable as deviations from normal conditions, and mission point, environmental, and aerodynamic information. The more classes of situations a pilot can recognize the more appropriate his behavior will be. But as the number of situation categories is increased so is the number of possibly defining facts. To avoid excessive examination of facts, most of which will turn out to have been irrelevant once the situation

†The Air Force's standard Boldface procedure does not even attempt to teach situation recognition; emergency situations are always obvious specific system failures. While Boldface seems appropriate for beginner pilots and should increase their survival rate, response performance could be improved by teaching branching policies, where actions are contingent upon previous events.

is recognized, the pilot can be taught certain generally important facts on the basis of which he could hypothesize a set of plausible emergency situations.
He could then determine which situation actually obtained by sequentially hypothesizing that he was in each plausible situation and then looking for the facts that that situation would lead one to expect.†
But even this last strategy cannot change the basic characteristic of this approach, which is that increased refinement is purchased at the price of increased processing time. In addition, since the instructors themselves presumably recognize situations by their similarity to unrationalized paradigms rather than by defining characteristics, the facts they single out to teach the trainees are at best approximations to whatever it is in the real situation which actually triggers the paradigm. For the above reasons one would expect this method of training to produce, at best, advanced novice behavior.

2. In a training procedure based on the intermediate model, the instructor gives the trainee detailed descriptions of examples of each type of emergency situation, including features and aspects, both relevant and irrelevant. This richly realistic detail presumably encourages the trainee

†This process of situation recognition has its parallel in recent developments in the field of artificial intelligence. In A.I. the formal representation of a type of situation is called a frame, script, or prototype. These complex data structures are accessed by means of defining cues and then themselves furnish hypotheses concerning what else to expect. See Minsky [20], Schank [21] and Winograd [22].

to become so involved that he creates emotion-laden images and thus builds up his own paradigm of each type of situation. The instructor discusses with the trainee how different descriptors for the features and aspects dictate different plans of recovery. He then helps the trainee formulate maxims which yield actions as functions of specific descriptors. The goal of this procedure is that, when an emergency of a type that has been taught occurs, the appropriate paradigm along with its associated maxim for action will spring to the trainee's mind. Training based on this procedure should yield virtually instantaneous situation recognition and the ability should degrade less over time than knowledge acquired through procedure one above, because skills are more permanently remembered and more easily reactivated than propositional knowledge. However, valuable time may be lost in remembering and applying the right maxim (and the maxims, being propositional knowledge, will degrade with time). Still, this procedure if successful would clearly be an improvement over procedure one, and should produce moderately skilled emergency response behavior.

3. In a procedure based on the situational model, the trainee would be encouraged to create many more paradigms than in procedure two above. Each paradigm would typify an emergency situation calling for one specific plan of recovery. The trainee would thus presumably acquire situation/action pairs and no longer need maxims. This procedure, if successful, would lead to highly skilled emergency re-

sponse behavior. Since no propositional knowledge is involved, this behavior would be least subject to degradation over time.

Situational Emergency Training, as developed by Thorpe et al. [23], can lead to either the kind of performance resulting from procedure one above or that resulting from procedures two and three. If the pilot listens with detachment to the situation description as a sequence of facts, the information presumably is processed as described by the nonsituational model. If, on the other hand, the pilot imaginatively places himself in the described situation and listens with involvement to the scenario, he presumably creates a paradigm which can later be used as the situational model describes.†

Every effort should be made to encourage the pilot's imaginative involvement. Holding training sessions in a cockpit procedures trainer (CPT), as suggested by Thorpe et al. [24], is a step in this direction. In addition, detached statements of the form "The plane is ..." should be avoided, and in every case replaced with involved statements of the form "You are ... ." Furthermore, past history of the flight should be included along with a detailed and complete description of the current situation in order to motivate the pilot's imaginative involvement.

†Assuming that imagining oneself in dangerous situations produces emotions, which can then be measured by various stress tests, our hypothesis that listening with involvement produces situational know-how which is remembered longer and produces better performance than propositional knowledge can be tested. One can correlate the quality of subsequent performance in a particular emergency situation with the degree of emotional involvement measured during situational training for that emergency.

VIII. SUMMARY

There are two fundamentally different explanations of skilled performance. While the desituationalized explanation seems to account adequately for what frequently occurs in acquiring a skill, it cannot account for highly skilled performance in a real world environment. The situational model, on the other hand, can account for the pronounced shift to more flexible and rapid performance that comes with experience. Psychological evidence suggests that a shift from propositional to holistic brain functioning (perhaps correlated with a change in hemispheres) underlies this change in behavior. Given the rapidity, reliability, and durability of these holistic processes, it follows that an emergency training procedure that makes use of holistic paradigms will lead to more proficient emergency behavior than a training program based on the nonsituational model.

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